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Classroom Ventilation Type and Pupil Learning

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INTRODUCTION

The air quality in school classrooms often suffers from too high occupant density and insufficient outdoor air supply (e.g. Menå & Larsen, 2010; Shendell et al., 2004; Daisey et al., 2003). Poor classroom air quality has been shown to reduce the performance of schoolwork (Bakó-Biró et al., 2012; Wargocki & Wyon, 2013), which may lead to a reduced learning outcome (Haverinen-Shaughnessy et al., 2011). In many countries, the progress in learning is routinely evaluated through standardized test schemes to benchmark both the performance of the individual pupils and the entire schools, as well as to evaluate the effectiveness of teaching methods and curricula. These test schemes offer a useful metric of the degree to which pupils acquire the knowledge as expected and are thus a useful indicator of their learning outcome. This pilot study examined associations between monitored CO₂ concentrations in the classrooms in Danish schools, the reported classroom ventilation mode and results of standardized tests performed by the pupils as part of a national test scheme.

METHODS

The analyses were conducted with outset in two large cross-sectional studies of indoor air quality in Danish schools. Altogether, data from 820 classrooms in 386 schools was used. One study comprised measurements in 311 elementary schools. One to sixteen classrooms per school (732 classrooms in total including classes from kindergarten to the 10th year) reported results on the indoor environment conditions. Each participating class conducted a spot-measurement of the CO₂ concentration with a Kitagawa 126SF measurement tube (range: 200-4000 ppm) at the end of a lesson. They were asked to keep the windows in the classroom closed during the lesson, while all other behaviour and installation settings remained unchanged.

In the second study, continuous measurements in one randomly selected classroom in 88 elementary schools were performed. The CO₂ concentration was monitored at 5 min intervals during 14 consecutive days with a Vaisala model GMW22 (range: 0-5000 ppm ± 100 ppm + 2% of reading) connected to a HOBO data logger model U12-012 that also monitored classroom temperature and relative humidity. In both studies the participants gave feedback on the classroom installations, including ventilation mode, room volume and occupancy.

In Denmark, a mandatory national test scheme routinely measures the academic performance of primary school pupils. For each school and classroom participating in the studies described above, we obtained results of standardized national test scores and an index for socioeconomic status to adjust the analyses for this covariate. All data was merged into one

dataset to analyze potential associations between the classrooms conditions, the ventilation mode, and pupil test performance. Mixed effects modelling was used for the analysis of data from the national test scheme. Data was clustered on schools and weighted with the number of pupils that represented a class test outcome.

RESULTS AND DISCUSSION

Figure 1 shows that the CO₂ concentration was significantly higher in schools with natural ventilation than in schools with mechanical exhaust or balanced mechanical ventilation. Despite the differences in the applied measurement methods between the two monitoring studies, the median CO₂ concentrations were comparable in schools with similar mode of ventilation, though the range of measured CO₂ concentrations was considerably larger when the pupils performed the measurements (Figure 1 left). The measurements confirm that school classrooms generally suffer from high CO₂ concentrations.

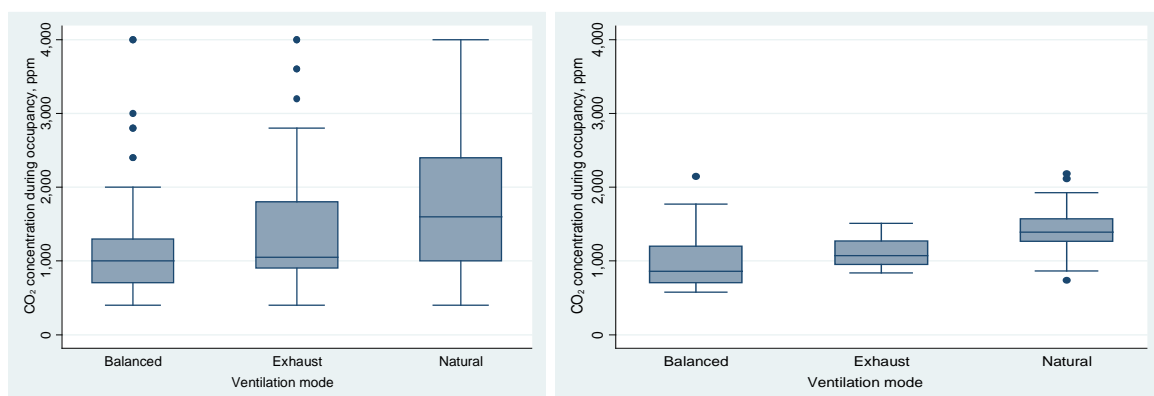


Figure 1. Box plots of CO₂ concentrations measured in the pupil run study in 732 classrooms (left) and with longer term measurements in 88 classrooms (right).

No significant association between the classroom CO₂ concentration and the results of the national tests was seen. However, there was a tendency that schools with the highest CO₂ concentration generally had the lowest test results. The measurements of CO₂ concentrations and the national test scores were merged retrospectively from several independent studies, which resulted in imperfect temporal alignment of the data for the indoor environment exposure and the pupils' test score. In the continued analysis we therefore used a school's ventilation mode as a proxy for the air quality.

A significant association between test performance and the ventilation mode of the schools was found with both the merged datasets and with data from schools included in the pupil run experiment. Pupils in schools with balanced mechanical ventilation typically had the highest test result, whereas schools with natural ventilation typically had the lowest test result. In the naturally ventilated schools, ventilation in the classroom depends on pupils' and teachers' airing behaviour, which may be very irregular resulting in an inferior classroom air quality as shown in Figure 1.

The available data did not indicate a significant association between the CO₂ concentration and the test performance, probably as a result of the CO₂ concentration being measured during short or relatively short periods in only one or a few classrooms at each school. The spatial and temporal variability in the CO₂ concentration within a school may thus have diminished the representativeness of this parameter in the current study. The ventilation mode

of a school was considered more time-invariant. The limited number of observations from the 88 schools with longer term monitoring was insufficient to reach statistical significance, but the mean test scores observed in these schools matched rather well the schools in the pupil run experiment.

Table 1. Average national test scores adjusted for socioeconomic status calculated for schools with different ventilation modes.

Ventilation type	Adjusted national test score (mean (s.d.))		
	Merged datasets	Schools with longer term monitoring	Pupil run experiment
Balanced	1.10 (6.6)	1.22 (6.8)	0.99 (6.4)
Exhaust	1.14 (9.2)	1.09 (6.5)	1.16 (10.1)
Natural	-0.35* (7.7)	-0.38 (7.6)	-0.29* (7.7)

* $p < 0.05$

The additional exploratory analyses did not detect any association between the test outcome and the person-specific room volume, the number of pupils in the class, construction/renovation year, or school location.

CONCLUSIONS

The CO₂ concentration was higher in Danish school classrooms with natural ventilation than in classrooms with mechanical exhaust or balanced mechanical ventilation. Pupils in schools with balanced mechanical ventilation typically had the highest scores in the national tests, whereas pupils in schools with natural ventilation typically scored lowest. Increasing evidence, including the results of the current study, indicates that insufficient classroom ventilation reduces the learning outcome.

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